Online Selection of $\pi^0(\eta) \rightarrow \gamma\gamma$ decays and the Potential for Intercalibrating the CMS Barrel Electromagnetic Calorimeter

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***Abstract*—Precise in situ calibration of the CMS electromagnetic calorimeter (ECAL) will be of crucial importance to fully exploit the physics reach of the CMS detector. In particular a precise calibration is needed to fully benefit from the excellent energy resolution of the calorimeter, approaching 0.5% for high energy unconverted photons. The resolution for photons is particularly important for the discovery of the Higgs boson in the two-photon decay channel. An inter-calibration technique based on low-mass resonance decays, $\pi^0(\eta) \rightarrow \gamma\gamma$, has been developed with simulated events, and was successfully tested with $\pi^0 \rightarrow \gamma\gamma$ decays collected at a CERN test beam. To accommodate the high rate of such decays at the LHC, a dedicated High Level Trigger (HLT) has been developed to select and store the events that can be used by this calibration algorithm.**

In this paper we describe this online procedure, including the regional unpacking of ECAL data and the selection procedure to be performed on the CMS HLT online computing farm, as well as the final calibration to be performed on the CERN Analysis Facility. In a low-luminosity scenario of the LHC, $\mathcal{L} = 2 \cdot 10^{30}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, we estimate that the majority of the barrel electromagnetic calorimeter can be inter-calibrated to 0.5% (1%) precision with $\pi^0(\eta) \rightarrow \gamma\gamma$ decays after a few weeks of data-taking.

***Index Terms*—CMS; ECAL; Calibration**

I. Introduction

THE Compact Muon Solenoid (CMS) barrel electromagnetic calorimeter consists of 61200 lead tungstate crystals arranged in 170 $\eta-$rings of 360 crystals each. The ECAL energy resolution has been determined in test beams to be $\frac{\sigma(\mathrm{E})}{\mathrm{E}} = \frac{2.8\%}{\sqrt{\mathrm{E(GeV)}}} \oplus \frac{0.12\ \mathrm{GeV}}{\mathrm{E}} \oplus 0.30\%$ [1], for electrons incident on the center of crystals. For electrons and photons with energies above 100 GeV, the energy resolution is dominated by the constant term. As a consequence, the performance of the CMS ECAL at the LHC will depend mainly on the quality of its calibration and monitoring. Achieving the design-goal calibration precision of 0.5% will be particularly important for a discovery of the Higgs boson in the decay channel $\mathrm{H} \rightarrow \gamma\gamma$, one of the primary goals of the LHC physics program.

An inter-calibration technique based on low-mass resonance decays, $\pi^0(\eta) \rightarrow \gamma\gamma$, has been developed with simulated collision data, and has been successfully tested with $\pi^0 \rightarrow \gamma\gamma$ decays collected at a CERN test beam [2]. To accommodate the high rate of these decays at the LHC, a dedicated High Level Trigger (HLT) is needed to select and store the events that can be used by this calibration algorithm.

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II. Online Selection for $\pi^0(\eta) \rightarrow \gamma\gamma$ candidates

A. Online Selection Method

The CMS physics trigger rate of about 100 Hz is not sufficiently high to collect a calibration sample for a fast crystal-by-crystal intercalibration to the designed precision with the time scale of a few weeks. Therefore we developed and optimized a selection method to select the $\pi^0(\eta) \rightarrow \gamma\gamma$ candidates directly from the events passing certain Level-1 (L1) triggers. A sample of about 41 million fully simulated Minimal Bias and pp $\rightarrow$ jets events is used for developing the online selection method. The low-luminosity scenario, $\mathcal{L} = 2 \cdot 10^{30}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, is assumed. One of the main goals of the optimization is to meet the network and timing budgets available for calibration purposes on the CMS online filter farm.

A regional unpacking sequence is used to meet the CPU constraint. The main idea is that only ECAL raw data around the L1 electromagnetic trigger objects with transverse momentum (P_T) greater than 2 GeV will be unpacked, and a collection of ECAL reconstructed objects, "Rechits", which contain the energy and position information of each crystal, will be made and used as an input for a specially designed filter module.

The purpose of this module is to quickly reconstruct the $\pi^0(\eta) \rightarrow \gamma\gamma$ candidates, apply initial selection cuts, and store useful Rechits for further selection and calibration that will be performed offline. The selections are based on a limited number of cuts on quantities computed using the crystal-level information from a localized region surrounding the $\pi^0(\eta)$ candidate, and are thus suitable for the demanding environment of the online filter farm.

B. Selection Results and Trigger Performance

The obtained invariant mass distribution is fitted to a combination of a Gaussian and a polynomial function (see Figure 1). The signal-to-background ratio (S/B) is estimated to be the ratio of the integral of the fitted signal and background function in the mass window, $M_{fit} - 2 \cdot \sigma_{fit} < M_{inv} < M_{fit} + 2 \cdot \sigma_{fit}$.

In the low-luminosity scenario of the LHC, $\mathcal{L} = 2 \cdot 10^{30}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ and $\sqrt{s} = 10$ TeV, the rate of signal $\pi^0(\eta) \rightarrow \gamma\gamma$ decays is estimated to be about 97 (6) Hz in the barrel

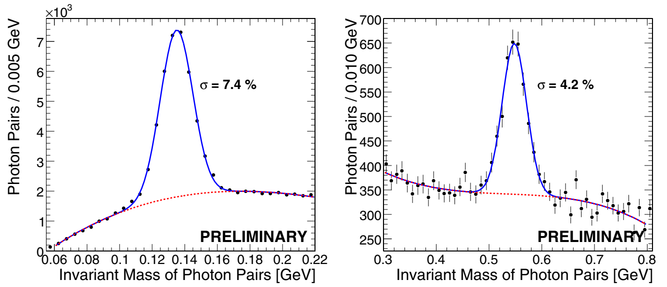

Fig. 1. The $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ (right) invariant mass distribution together with the results of the fit to a combination of a Gaussian and a polynomial.

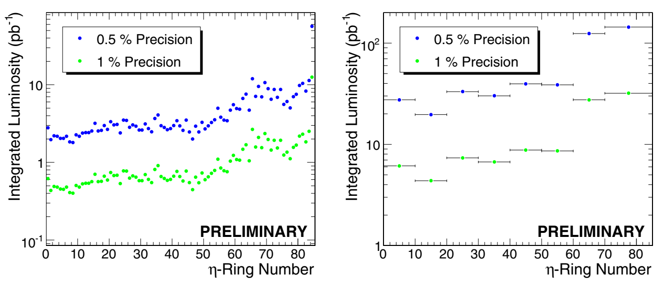

Fig. 2. Number of data required to achieve calibration precisions of 1% and 0.5% for crystals in different η-rings, with π^0 and η (right) calibration.

ECAL, with S/B value about 1.9 (0.5). The average energy of photons from the selected $\pi^0(\eta)$ decays are found to be about 2.7 (4.7) GeV. The event rate is ~0.4 kHz, which translates into less than 1 MB/s in terms of bandwidth consumption between the online filter farm and the CERN Analysis Facility (CAF), where the calibration will be performed. The CPU time spent on this trigger path is found to be ~2 ms per event.

III. Calibration with $\pi^0(\eta) \to \gamma\gamma$ Decays

Several calibration algorithms have been studied and found to produce consistent results. One of them is described below.

For a given crystal, the invariant mass distribution is obtained from all $\pi^0(\eta)$ candidates for which one of the photons is centered on this crystal. Iteratively, the calibration constants are updated according to the peak positions of such distributions. The energy and direction of each photon candidate are recalculated using the updated calibration constants.

Initial miscalibrations were chosen randomly for each channel, (i.e. The signal for that channel was multiplied by a value 1+d, where d was chosen from a Gaussian distribution with a mean of 0 and a width of 0.04). The calibration precision is then estimated as the R.M.S. of the distribution of the products of the initial miscalibration and final calibration constants.

A. Performance of the $\pi^0(\eta) \to \gamma\gamma$ Calibration

Before crystal-to-crystal calibration, a correction depending on η and ϕ index of crystals is applied in order to remove the systematic effects due to the gaps between the ECAL modules and due to the dependence of shower containment on energy and pseudorapidity.

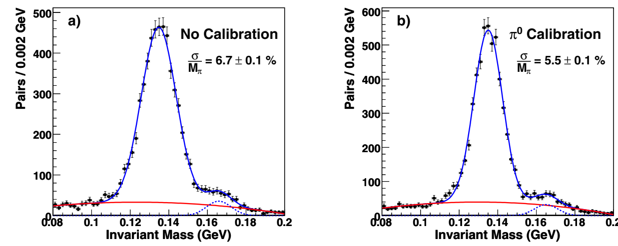

Fig. 3. Reconstructed π^0 mass peak a) before and b) after applying the π^0 calibration constants. Each distribution was fitted to a double-gaussian plus a second order polynomial function and the obtained peak resolution is indicated on the plots.

The dependence of the calibration precision on the number of selected signal decays S, and S/B value is determined by varying S and S/B separately. Then we translate the obtained results into the time needed to achieve a given level of calibration precision for different η regions of the ECAL. We estimate that the majority of the barrel ECAL can be inter-calibrated to at least a 0.5% (1%) precision after a few weeks of data-taking in the low-luminosity scenario of the LHC, $\mathcal{L} = 2 \cdot 10^{30}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ (Fig. 2), assuming that 1-2 pb^{-1} data per day will be recorded.

Intercalibration with $\eta \to \gamma\gamma$ decays is expected to be much slower than intercalibration with $\pi^0 \to \gamma\gamma$ decays, it will however to be a very valuable cross check. In addition, because of higher energy, photon reconstruction from η decays will be less affected by the experimental systematics.

B. π^0 Calibration in Test Beams

Further calibration studies were carried out using π^0 decays produced in the π^- test beam runs performed in November 2006 (see Figure 3). The average energy of the selected π^0 candidates is found to be about 8 GeV. Using a sample of approximately 140 π^0's per crystal we achieve a calibration precision of $1.0\pm0.1\%$, which is consistent with the statistics-limited expectation of 0.9%. Thus, no noticeable limiting factors on the calibration performance are observed. This study also confirms that the CMS ECAL is capable of reconstructing the low-energy photons produced in $\pi^0 \to \gamma\gamma$ decays. In addition, it has been verified that the calibration constants obtained from π^0 calibration can be applied at higher energy (e.g. 50 GeV electrons) without loss of accuracy.

IV. Conclusions

We have presented an online selection method for selecting events with $\pi^0(\eta) \to \gamma\gamma$ decays and the potential for intercalibrating the CMS barrel ECAL. The online selection method has been optimized to meet the stringent requirements imposed by the CMS online farm. We estimate that the majority of the barrel calorimeter can the be inter-calibrated to at least a 0.5% (1%) precision after a few weeks of continuous data-taking in the low-luminosity scenario of the LHC with $\pi^0(\eta)$ calibration. The π^0 calibration technique has also been successfully applied to the test beam data.

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REFERENCES

[1] S. Chatrchyan *et al.* [CMS ECAL Collaboration], "The CMS experiment at the CERN LHC", JINST 3 S08004 (2008)
[2] P. Adzic *et al.* [CMS ECAL Collaboration], "Intercalibration of the barrel electromagnetic calorimeter of the CMS experiment at start-up", JINST 3 P10007 (2008)